

Europäisches Patentamt
European Patent Office
Office européen des brevets



(11) EP 0 748 038 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
11.12.1996 Bulletin 1996/50

(51) Int. Cl.⁶: H02P 6/10

(21) Application number: 96108215.3

(22) Date of filing: 23.05.1996

(84) Designated Contracting States:
CH DE FR GB IT LI

(30) Priority: 05.06.1995 US 461265
13.05.1996 US 645380

(71) Applicant: KOLLMORGEN CORPORATION
Waltham, MA 02154 (US)

(72) Inventors:

- Ohm, Dai Yong
Blacksburg, VA 24060 (US)
- Chava, Venkatesh Babu
Germantown, Maryland 20874 (US)

(74) Representative: Königseder-Egerer, Claudia D.
Kreuzbühl 1
82491 Grainau (DE)

(54) System and method for controlling brushless permanent magnet motors

(57) A system and method of calculating optimum angle advance for brushless permanent magnet motors is claimed. The calculations are based on the motor drive parameters and on operational variables including the motor speed and the motor load. The angle advance is calculated dynamically as a function of motor speed and, where reluctance torque is involved, as a function of load current as well. For a given motor, the angle advance is calculated according to the speed and load together with the motor and drive parameters according to one or more angle advance equations.

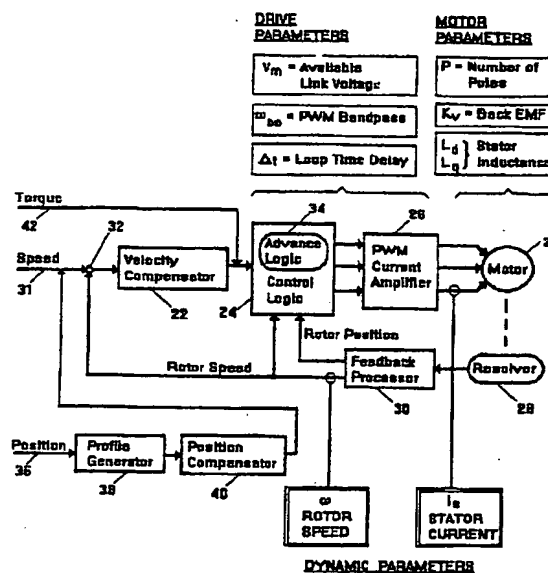


FIG. 1

EP 0 748 038 A2

Description

This invention relates to electric motors, and more particularly to control systems for brushless permanent magnet motors.

BACKGROUND OF THE INVENTION

A brushless permanent magnet motor typically includes windings on the stator, rotating permanent magnets, and a position sensor for indicating the rotor position. The winding energization is generally controlled by solid state switches that are responsive to the position indications to energize the windings in the proper commutated sequence. Motor control is achieved by controlling the magnitude of the winding excitation current.

US-A-4,447,771 (the '771 patent) describes a system in which both the phase and magnitude of a motor's winding excitation currents are controlled. A quadrature phase relationship normally exists between the rotor field and the rotating stator magnetic field. The phase angle is varied from the quadrature relationship according to "torque angle factors" which are a function of the motor speed. By dynamically varying the phase angle, an improved motor performances over a wide speed range.

In a manner similar to the '771 patent, US-A-4,490,661 (the '661 patent) employs "torque angle factors" to vary the phase relationship between the rotor field and the rotating stator magnetic field as a function of both the motor speed and motor load.

The typical calibration procedure for arriving at the torque angle factors used in determining the angle advance in the '771 and '661 patents would use a test motor and drive, a three phase Variac, a dynamometer, and a blower for cooling the motor. The three phase Variac was used to provide the three phase power necessary to excite the stator. The dynamometer was used to measure the motor's torque. To determine the angle advance for a given speed, the motor was set to the speed and allowed to stabilize at a predetermined test temperature, the blower being used to regulate the motor temperature. Once stable speed and temperature were achieved, the angle advance was manually adjusted while observing the dynamometer reading to determine the angle that gives the maximum torque. The calibration procedure was repeated for the desired number of motor speeds and/or loads to create a table of torque angle factors. The calibration procedure would be repeated for each motor type, and in some cases, for each motor. The prior calibration method was costly and time consuming and provided torque angle values for only a finite number of motor speeds.

SUMMARY OF THE INVENTION

The present invention provides a system and method for determining the best angle advance for any set of motor speed and/or load conditions, without engaging in a lengthy calibration procedure. The calculations are based on certain motor and drive parameters. The motor parameters include a number of poles P , the back emf K_v , and the stator inductance values L_d and L_q . The drive parameters include the bandpass of the PWM (pulse width modulation) amplifier ω_{bp} , the control loop time delay Δt and the available link supply voltage V_m . These motor and drive parameters can be used according to the invention to determine the optimum phase advance for the dynamic variables of rotor speed ω and stator current I_s . The angle advance values calculated from the motor and drive parameters can be recorded in a look-up table as functions of the dynamic factors of rotor speed and/or motor load.

In one implementation of the preferred embodiment of the invention, discrete logic or a microprocessor is used to compute the angle advance and control the winding excitation currents accordingly. In the microprocessor implementation, a program stored for use in the microprocessor, is used to calculate the angle advance. The calculations are based on a rotor position feedback signal supplied by one or more sensors, a rotor velocity feedback signal which can be derived from the position feedback signal, and a measure of stator current which is proportional to torque. The microprocessor computes the optimum angle advance for any combination of speed, rotor position and torque.

These and other objects are achieved by the method and system for controlling brushless permanent magnet motors as claimed in Claims 1 to 14.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a functional block diagram of a motor control system in accordance with the invention.

Fig. 2 is a functional block diagram of a control logic unit suitable for use in the motor control system of Fig. 1.

Fig. 3 is a schematic diagram of a PWM current amplifier suitable for use in the motor control system of Fig. 1.

Fig. 4 is an illustration of the relationship between the sinusoidally varying excitation signals and the corresponding pulse width modulated (PWM) outputs of the current of Fig. 3.

Fig. 5 is a cross section of a brushless permanent magnet motor wherein the magnets are embedded in the rotor.

Fig. 6A shows the q-axis dynamic equivalent circuit for an IPM motor.

Fig 6B shows the d-axis dynamic equivalent circuit for an IPM motor.

$$\psi_{mag a} = \psi_{mag} \cos \theta \quad (A.13)$$

$$\psi_{mag b} = \psi_{mag} \cos (\theta - 120) \quad (A.14)$$

$$\psi_{mag c} = \psi_{mag} \cos (\theta + 120) \quad (A.15)$$

Input power P_i can be represented as:

$$P_i = V_a I_a + V_b I_b + V_c I_c \quad (A.16)$$

Output power P_o and the output torque T cannot be expressed in a simple form in the three phase model. An expression which ties the two parameters together is:

$$T = (P/2)P_o/\omega \quad (A.17)$$

By letting S represent the quantity (current, voltage and flux linkage) to be transformed from the abc frame to the d-q frame, the following matrix transformation is derived:

$$\begin{bmatrix} S_q \\ S_d \\ S_o \end{bmatrix} = (2/3) \begin{bmatrix} \cos \theta & \cos(\theta - 120) & \cos(\theta + 120) \\ \sin \theta & \sin(\theta - 120) & \sin(\theta + 120) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} \quad (A.18)$$

In a balanced three phase system, the S_o component, or "zero sequence component", is always zero.

Since the transformation is linear, its inverse transformation exists and is given by:

$$\begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} = \begin{bmatrix} \cos \theta & \cos \theta & \cos(\theta + 120) & 1 \\ \cos(\theta - 120) & \sin(\theta - 120) & \sin(\theta + 120) & 1 \\ \cos(\theta + 120) & \sin(\theta + 120) & 0.5 & 1 \end{bmatrix} \begin{bmatrix} S_q \\ S_d \\ S_o \end{bmatrix} \quad (A.19)$$

By applying the transformation of equation A.18 to the voltages, flux linkages and currents of equations A.1 - A.6, a simple model for the d-q electrical dynamic equations and flux-linkage equations is derived:

$$V_q = R_s I_q + p\psi_q + \omega\psi_d \quad (A.20)$$

$$V_d = R_s I_d + p\psi_d - \omega\psi_q \quad (A.21)$$

$$\psi_q = L_q I_q \quad (A.22)$$

$$\psi_d = L_d I_d + \psi_{mag} \quad (A.23)$$

L_q and L_d are called d and q axis inductances, respectively, and they are defined as:

$$L_q = (3/2)(L_{so} + L_x) + L_{sl} \quad (A.24)$$

$$L_d = (3/2)(L_{so} - L_x) + L_{sl} \quad (A.25)$$

By eliminating flux-linkage terms from equations A.20 - A.23, the following equations are derived:

$$V_q = (R_s + L_q p) I_q + \omega L_d I_d + \omega \psi_{mag} \quad (A.26)$$

$$V_d = (R_s + L_d p) I_d - \omega L_q I_q \quad (A.27)$$

Equations A.26 and A.27 form the basis for the d-q model for brushless permanent magnet motors. The d-q equivalent circuit that represents the model is shown in Figs. 6A and 6B.

Another assumption made in computing the amplifier phase delay is that the most practical amplifier can be modeled as a first order amplifier of the form:

$$G(s) = \frac{Ka}{s/\omega_b + 1} \quad (\text{B.11})$$

In the above equation, Ka is the amplifier DC gain, which has no bearing on the phase delay calculation. Now, the phase lag due to the amplifier is given by:

$$\theta_{s2} = \arctan(\omega/\omega_b) \quad (\text{B.12})$$

When the system is in generation mode, the sign of ω in equation B.10 is negative, and ω_b is higher than ω_{bo} , resulting in a very small θ_{s2} . Therefore, the speed angle advance required for generation mode is smaller than that required for motoring mode.

In accordance with equations B.9 and B.12 the desired speed angle advance may be written as

$$\theta_s = \theta_{s1} + \theta_{s2} = (180/\pi)\Delta t \omega + \arctan(\omega/\omega_b) \quad (\text{B.13})$$

Thus, the speed angle advance may be calculated from the knowledge of Kv , ω_{bo} , V_m , Δt and ω . Parameters Kv and ω_{bo} are associated with the motor, while parameters V_m and Δt may be derived from the drive characteristics. As in the case of load angle advance, an array of optimal θ_s vs. speed can be calculated upon motor initialization.

3) The Angle Advance Curves for Speed and Load

The load angle advance curve described by equation B.8 is shown in Fig. 7A. The speed angle advance curves are shown in Fig. 7B. In accordance with the description of equation B.13, Fig. 7B shows two speed angle advance curves, one for motoring mode, and one for generating mode.

The optimum angle advance for a given mode of operation, rotor speed, and stator current may be determined from inspection of Figs. 7A and 7B. The mode and speed may be used in conjunction with Fig. 7B to yield a value for the speed angle advance, while the current may be used in conjunction with Fig. 7A to yield a value for the load angle advance. The two values are then added to determine the optimum advance.

The curve for angle advance as a function of stator current shown in Fig. 7A is typical for an embedded permanent magnet (IPM) motor. The comparable curve for a surface permanent magnet (SPM) motor is typically a flat zero curve, meaning that no angle advance correction as a function of stator current is required.

In the embodiment described above and depicted in Figures 1, 2 and 3, the angle advance may be computed dynamically by performing the calculations of equations B.8 and B.13. However, if the control logic unit does not have the capacity to compute the angle advance dynamically, a look-up table may be employed. In such a configuration, the look-up table contains a precalculated list of angle advances formulated from equations B.8 and B.13. Separate look-up tables could be used for load advance, speed advance in generating mode, and speed advance in motoring mode. During motor operation, the advance logic unit would use the tables to "look-up" the angle advance corresponding to the present torque command value, rotor speed, and operating mode. The look-up tables obviate the complex calculations of equations B.8 and B.13 on an ongoing basis. The look-up table approach has the disadvantage of requiring considerable set up time.

Interpolation may be used in conjunction with one or more look-up tables. Interpolation increases the efficiency of a look-up table configuration by providing approximations of exact angle advance for operating conditions other than those specified in the table. The complexity of the interpolation algorithm employed may be varied to trade off accuracy of calculation and calculation speed.

In another embodiment, neither "on the fly" computation of equations B.8 and B.13 nor "look-up" tables are employed. Instead, equations B.8 and B.13 may be approximated through curve fitting based on a limited set of precalculated values. Curve fitting may yield equations that are simpler to calculate than equations B.8 and B.13, thus allowing them to be calculated "on the fly". As with interpolation, the complexity of the curve fitting equations may be varied to trade off between accuracy of calculation and calculation speed.

In another embodiment of the invention, an integrated circuit processor, such as a microprocessor or digital signal processor is incorporated into control logic unit 24. To implement such a system: the torque command is converted to a digital signal prior to being passed to the processor. The functions of the angle calculation circuit 46, advance logic unit 34, phase offset 50, and sine tables 48 and 52 as shown in Fig. 2 are coded into the processor's software. The D/A converters 54 and 56 are located at a point between the microprocessor and the PWM current amplifier. The profile generator, position compensator, velocity compensator, feedback processor may also be functions performed in the

microprocessor.

In some cases, it is useful to compensate for stator current drop-off due to approaching saturation at high torque operation. The current drop-off refers to the reduction in motor current that occurs with incremental increases in motor speed. A technique that may be used to compensate for stator current drop-off is described below. The compensation technique is described in relation to the embodiment illustrated in Figs. 1 to 3.

Stator current drop-off is related to the Current amplifier portion of the motor drive. As was discussed above, the amplifier can be modeled as a first order amplifier having the transfer function (B.11):

$$G(s) = \frac{K_a}{s/\omega_b + 1} \quad (\text{B.11})$$

where ω is the electrical frequency corresponding to the speed of the rotor, ω_b is the bandwidth of the current loop at speed ω , and K_a is the amplifier DC gain. It follows that the magnitude, M , of the amplifier transfer function is:

$$M = \frac{K_a}{\sqrt{(\omega/\omega_b)^2 + 1}}$$

Thus, the magnitude of the amplifier output decreases as motor speed increases. The speed angle advance of equation B.13 does not account for the magnitude drop-off associated with the current amplifier, but rather accounts only for the phase delay associated with the amplifier. One way to compensate for the stator current drop-off is to modify the control logic unit of Fig. 2.

Fig. 8 shows how the control logic unit of Fig. 2 can be modified to add a magnitude boost unit 33. The magnitude boost unit compensates for the stator current drop-off by multiplying the torque command by the inverse of the amplifier transfer function magnitude ($1/M$). This has the effect of increasing the output of DAC 58 by $1/M$ and, in turn, increasing the output of DACs 56 and 54 by $1/M$. Accordingly, the currents phase A, phase B and phase C that are passed to the current amplifier are increased by a factor of $1/M$, and the net result is that the stator current entering summing junction 60 (Fig. 3) is increased by a factor of $1/M$. This increase compensates for the stator current drop-off.

As previously mentioned, equations B.8 and B.13 may be used to dynamically compute the angle advance. To solve these equations, the parameters indicated in Fig. 1 are required. The required motor parameters are L_d and L_q (stator inductances), P (the number of poles) and K_v (the back emf constant). The required drive parameters are ω_b (the PWM bandpass), Δt (the loop time delay) and V_m (the available link voltage). The required dynamic parameters are ω (the rotor speed) and I_s (the stator current). In an adaptive controller implementation, the required motor parameters and drive parameters are established during initialization of the system and then used in calculating the angle advance according to the dynamic parameters of rotor speed and stator current while in operation.

The dynamic parameter ω (rotor speed) may be measured using resolver 28, and the dynamic parameter I_s (stator current) may be measured by a suitable current sensor located to measure current supplied to the motor.

Regarding Δt , in most applications, the loop time delay Δt is negligible and, therefore, drops from the equations. Where required, the loop time delay can be measured by passing a test pulse through the system and measuring the delay during the initialization.

Regarding V_m , this parameter may be determined from the DC link voltage, V_{dc} . The relationship between V_m and V_{dc} is dependent on the method of modulation. For sinusoidal-triangle modulation, $V_m = 0.78 V_{dc}$.

Regarding K_v , this parameter is generally available from the manufacturer's data sheet and may be entered manually during initialization, for example, through data key entry. Alternatively, K_v could be determined by driving the motor at a fixed speed, such as 20% of the nominal speed, and measuring the voltage generated under these conditions. When measuring the voltages, no angle advance should be used. Other methods for determining K_v from instantaneous voltages are also well known.

Regarding ω_b , this parameter can be determined by locking the motor shaft and exciting the controller with a sinusoidal torque command. The sinusoidal input command is swept from approximately 1 Hz to 1 KHz while the output of the controller is measured. The bandpass parameter ω_b is the frequency at which the magnitude of the measured output is 3dB down from the peak value.

At this point, the parameters required by the equation that remain to be determined are ψ_{mag} (peak flux linkage due to permanent magnet), and L_d and L_q (stator inductances). For each of these parameters, two methods of calculation are presented. In each case, the first method involves fewer steps than the second, but the second method provides a more precise determination of the parameter.

For a simplified determination of ψ_{mag} , the value of K_v may be inserted into the following equation to yield a value for ψ_{mag} :

$$\psi_{mag} = \sqrt{2/3} (2/P) K_v$$

For simplified determinations of the stator inductances L_d and L_q the following procedure may be employed. First, the stator resistance, R_s , is measured. This is done by applying a small amount of DC voltage, V_i , into the motor and measuring the resulting current, i_i . R_s is equal to V_i/i_i . Next, a three-phase step current is injected into the q-axis at zero speed and the rise time, Tr_q , is measured. Once R_s and Tr_q are known, L_q may be calculated from the equation;

$$L_q = Tr_q R_s$$

Similarly, a three-phase step current may be injected into the d-axis at zero speed and the rise time, Tr_d , measured. L_d is given by:

$$L_d = Tr_d R_s$$

For more precise determinations of ψ_{mag} , L_d and L_q , the following equations may be used:

$$\begin{aligned} L_q &= L_{qo}(a+1)/(a+k) \\ L_d &= L_{do}(b+1)/(b+k) \\ \psi_{mag} &= \psi_{mago} (c+1)/(c+k) \end{aligned}$$

Where

L_{qo} is the q-axis self inductance at rated stator current
 L_{do} is the d-axis self inductance at rated stator current
 ψ_{mago} is the peak flux linkage at rated stator current
 a, b and c are constants determined by the saturation characteristics of the motor
 $k = I_s/I_{so}$
 I_{so} is the rated stator current
 I_s is the actual stator current

To determine the value of constants a, b and c , L_d and L_q are each measured at two or more stator current values. Preferably, L_d and L_q are measured at the rated stator current and at three times the rated stator current ($k=3$). If at the rated current, a value of L_{qo} is obtained for L_q , and at three times the rated current a value of L_{q1} is obtained for L_q , then a is given by:

$$a = (kL_{q1} - L_{qo}) / (L_{qo} - L_{q1})$$

Similarly, b will be given by:

$$b = (kL_{d1} - L_{do}) / (L_{do} - L_{d1})$$

The value $c=b$, since c and b relate to the same d-axis flux path. ψ_{mago} is given from K_v , as in the simplified calculation.

Fig. 9 depicts a circuit that may be used to measure the q-axis and d-axis inductances at various stator currents. In the circuit, each phase winding (A, B and C) of a three-phase motor 95 is coupled to a DC power supply 96. A three-phase contactor 97 is coupled between the motor 95 and power supply 96 for the purpose of short-circuiting the three-phase lines. A shunt resistor 98 is connected in the phase A line of the motor for the purpose of facilitating oscilloscope measurement. The circuit may be used to implement the following method of measuring L_q and L_d .

The q-axis inductance, L_q , is measured first. To measure the q-axis inductance, the positive terminal of the DC power supply is connected to the phase B winding of the motor, and the negative terminal of the DC power supply is connected to the phase C winding of the motor. The A winding of the motor is allowed to float, and the motor shaft is allowed to rotate freely. After the foregoing preparation have been made, the DC power supply is turned on and the output voltage is increased until the output current reaches about 1/4 of the rated stator current. The motor shaft should be allowed to settle into a stable position, and once stabilized, the shaft should be locked. Next, the phase A winding is connected to the positive terminal of the DC power supply, and both the B and C windings are connected to the negative terminal of the DC power supply. The DC supply voltage is increased until the DC supply output current reaches a desired level. Preferably, the supply voltage is increased to a level at which the A winding current is 1.41 times the rated stator current (rms). When the DC output current reaches the desired level, the three-phase contactor is activated and the decay time of the output current is measured. The decay time is defined as the amount of time it takes the output

f) means for computing a maximum torque angle advance according to said measured motor and controller parameters as a function of said velocity feedback signal and said stator current feedback signal;

g) means for generating a sinusoidal excitation for the stator winding having a frequency according to said velocity feedback and a phase according to said maximum torque angle advance.

2. The controller of claim 1 wherein said motor parameters include the number of poles, the back emf constant, and the stator inductance for the motor.

3. The controller of claims 1 or 2 wherein said controller parameters include the controller bandpass, the available link voltage, and the loop time delay.

4. The controller of claim 1 wherein said permanent magnets are embedded in said rotor and wherein said maximum torque angle advance varies as a function of rotor velocity and stator current.

5. The controller of claim 1 wherein said permanent magnets are surface mounted in said rotor and wherein said maximum torque angle advance varies as a function of rotor velocity.

6. A method for controlling a brushless motor including a permanent magnet rotor and a stator winding, comprising the steps of

a) generating a position feedback signal indicative of the rotor position relative to the stator;

b) generating a velocity feedback signal indicative of the rotor velocity;

c) providing a stator current feedback signal indicative of the current supplied to the stator winding;

d) indicating measured values of motor parameters;

e) indicating measured values of controller parameters;

f) computing a maximum torque angle advance according to said measured motor and controller parameters as a function of said velocity feedback signal and said stator current feedback signal; and

g) generating a sinusoidal excitation for the stator winding having a frequency according to said velocity feedback and a phase according to said maximum torque angle advance.

7. The method of claim 6 wherein said motor parameters include the number of poles, the back emf constant, and the stator inductance for the motor.

8. The method of claims 6 or 7 wherein said controller parameters include the controller bandpass, the available link voltage, and the loop time delay.

9. The method of claim 6 wherein said permanent magnets are embedded in said rotor and wherein said maximum torque angle advance varies as a function of rotor velocity and stator current.

10. The method of claim 6 wherein said permanent magnets are surface mounted in said rotor and wherein said maximum torque angle advance varies as a function of rotor velocity.

11. A method for controlling a brushless motor including a permanent magnet rotor and a stator winding, comprising the steps of

a) generating a position feedback signal indicative of the rotor position relative to the stator;

b) generating a velocity feedback signal indicative of the rotor velocity;

c) providing a stator current feedback signal indicative of the current supplied to the stator winding;

d) indicating measured values of motor parameters;

e) indicating measured values of controller parameters;

f) computing a maximum torque angle advance according to said measured motor and controller parameters as a function of said velocity feedback signal; and

g) generating a sinusoidal excitation for the stator winding having a frequency according to said velocity feedback and a phase according to said maximum torque angle advance.

12. A method of compiling a look-up table providing maximum torque angle advance values for controlling the phase of the sinusoidal excitation for a brushless motor with rotating permanent magnets and a stator winding, comprising the steps of

- a) measuring motor parameters including the number of poles, the back emf constant, and the stator inductance for the motor;
- b) measuring controller parameters including the controller bandpass, the available link voltage, and the loop time delay;
- c) calculating phase advance values according to said measured parameters as a function of rotor velocity;
- d) setting the phase of the sinusoidal excitation according to said phase advance values corresponding to the rotor velocity.

13. A method of compiling a look-up table providing maximum torque angle advance values for controlling the phase of the sinusoidal excitation for a brushless motor with rotating permanent magnets and a stator winding, comprising the steps of

- a) measuring motor parameters including the number of poles, the back emf constant, and the stator inductance for the motor;
- b) measuring controller parameters including the controller bandpass, the available link voltage, and the loop time delay;
- c) calculating phase advance values according to said measured parameters as a function of rotor velocity;
- d) setting the phase of the sinusoidal excitation according to said phase advance values corresponding to the rotor velocity and stator current.

14. A controller for a brushless motor including a moving permanent magnet arrangement and a stator winding, comprising

- a) means for generating a position feedback signal indicative of the rotor position relative to the stator;
- b) means for generating a position feedback signal indicative of the permanent magnet arrangement velocity;
- c) means for providing a stator current feedback signal indicative of the current supplied to the stator winding;
- d) means for indicating measured values of motor parameters;
- e) means for indicating measured values of controller parameters;
- f) means for computing a maximum torque angle advance according to said measured motor and controller parameters as a function of said velocity feedback signal and said stator current feedback signal;
- g) means for generating a sinusoidal excitation for the stator winding having a frequency according to said velocity feedback and a phase according to said maximum torque angle advance.

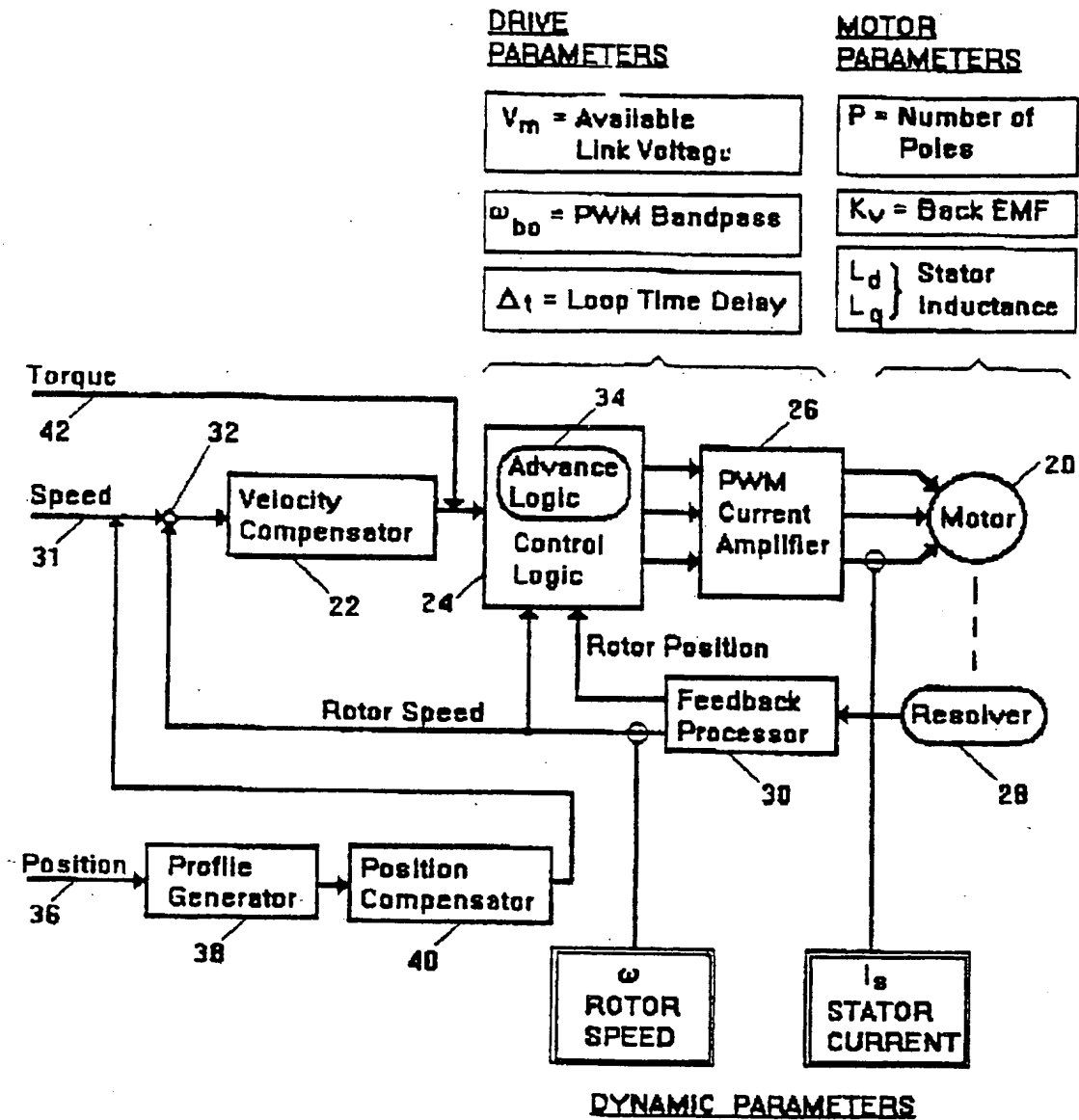


FIG. 1

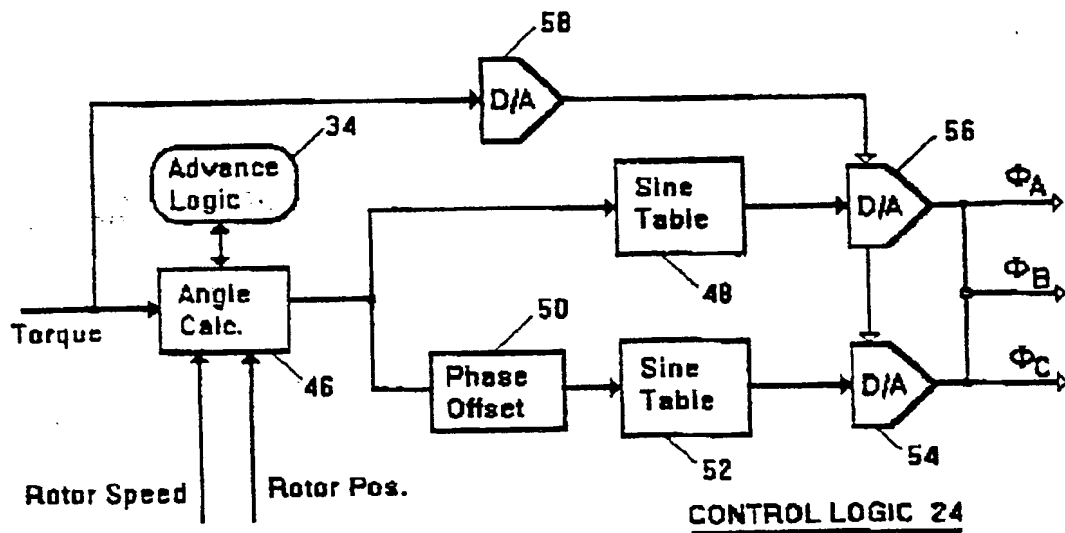


FIG. 2

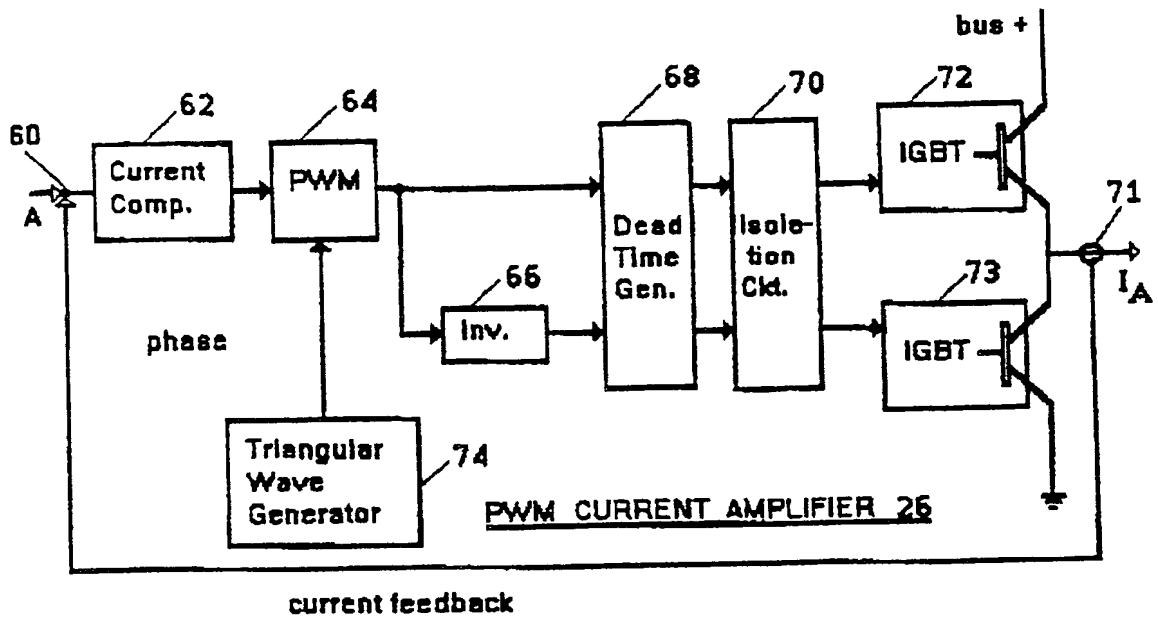


FIG. 3

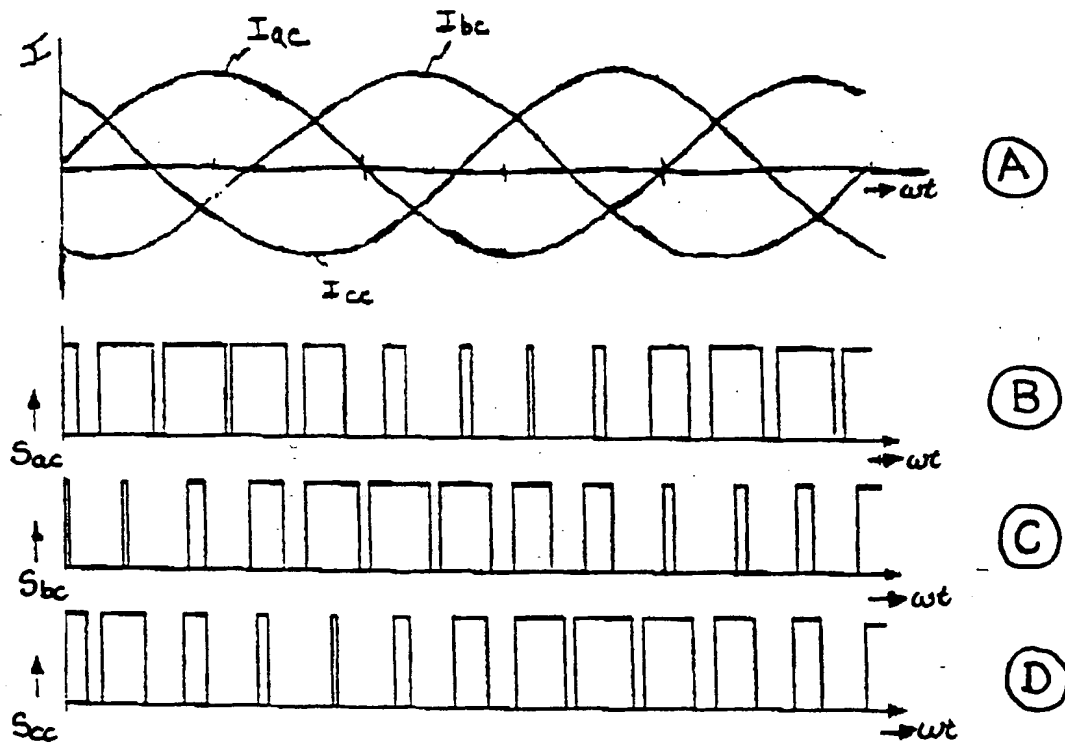


FIG. 4

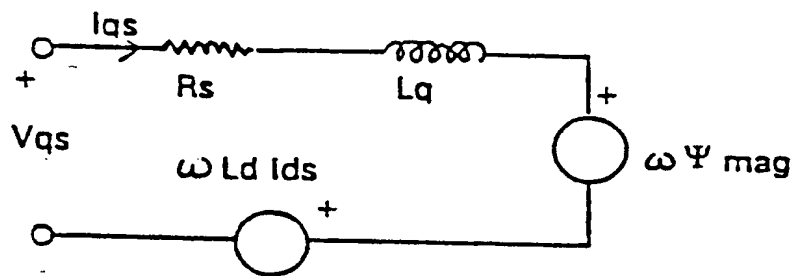


FIG. 6A

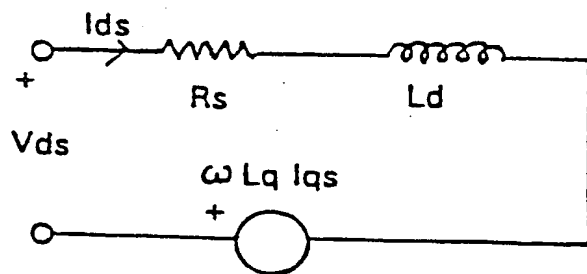


FIG. 6B

FIG. 7A

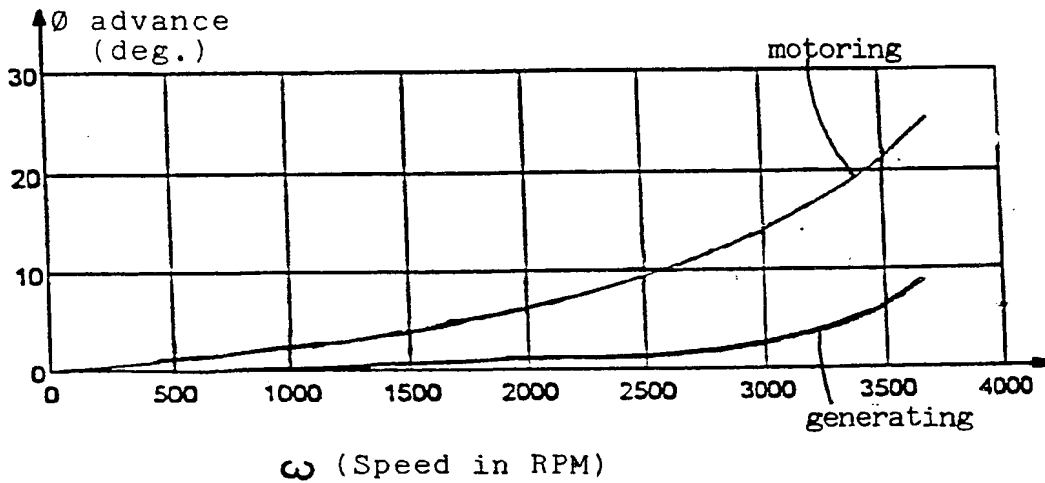
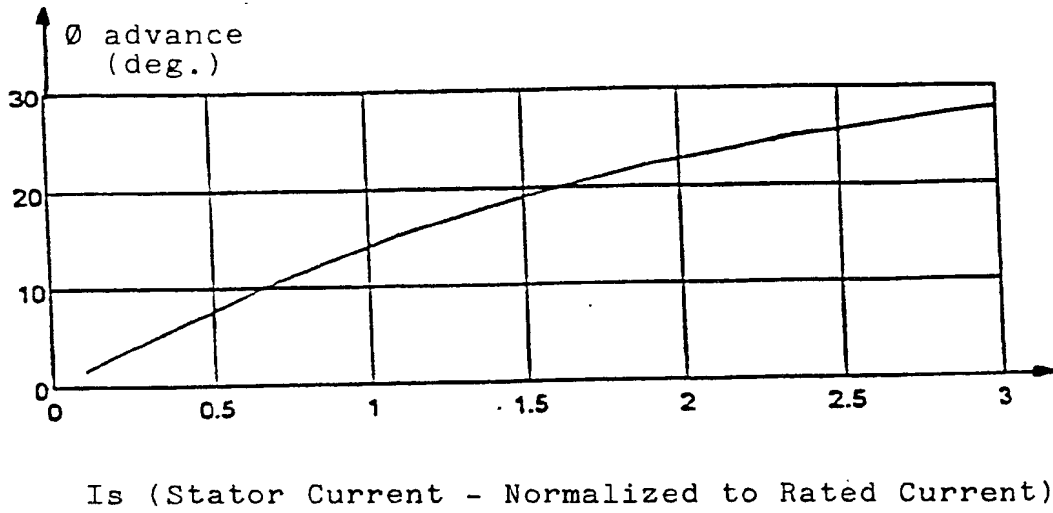


FIG. 7B

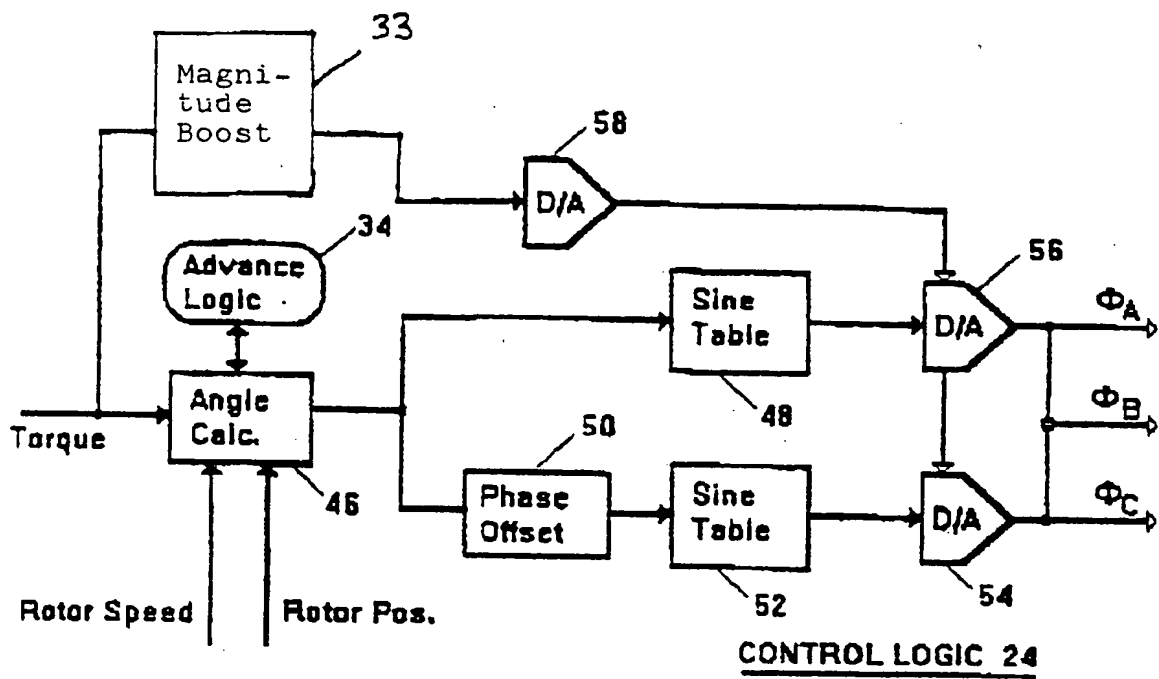


FIG. 8

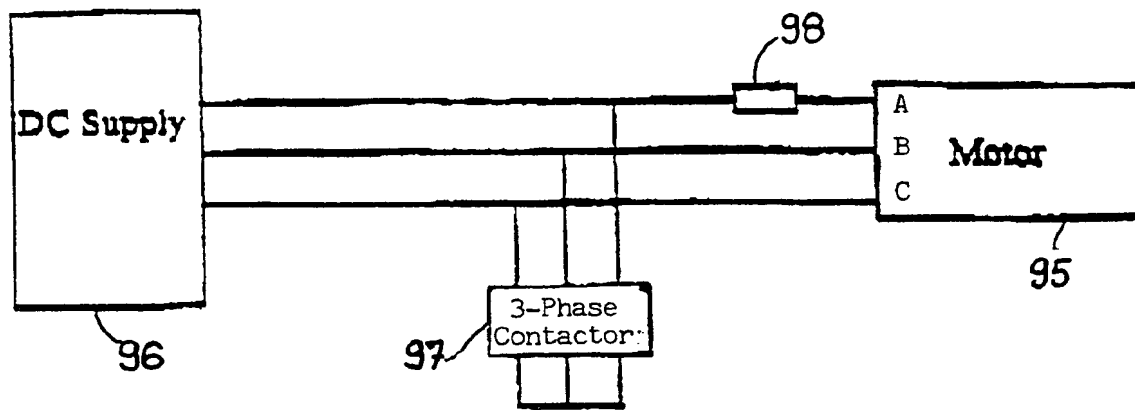


FIG. 9

FIG. 10A

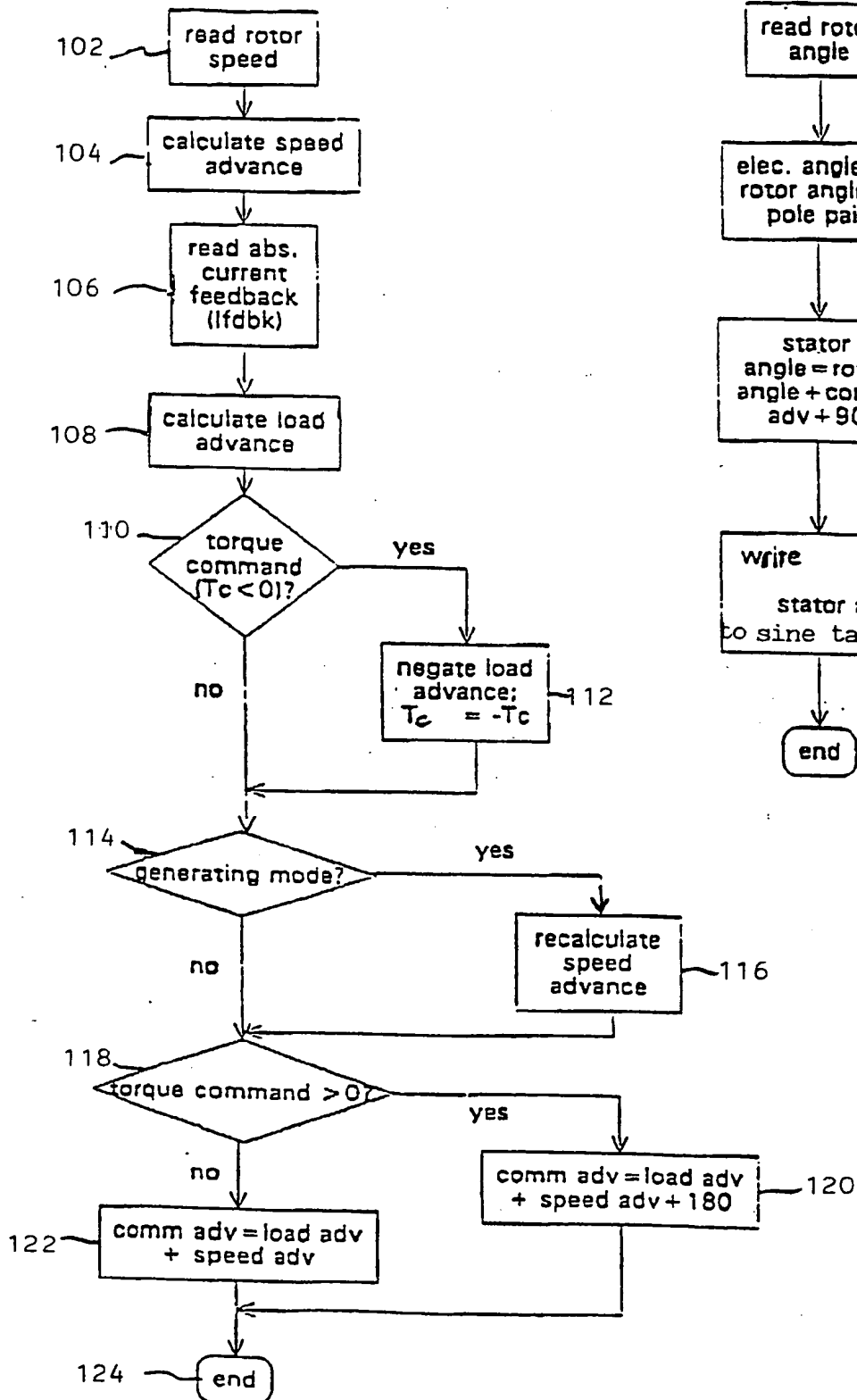
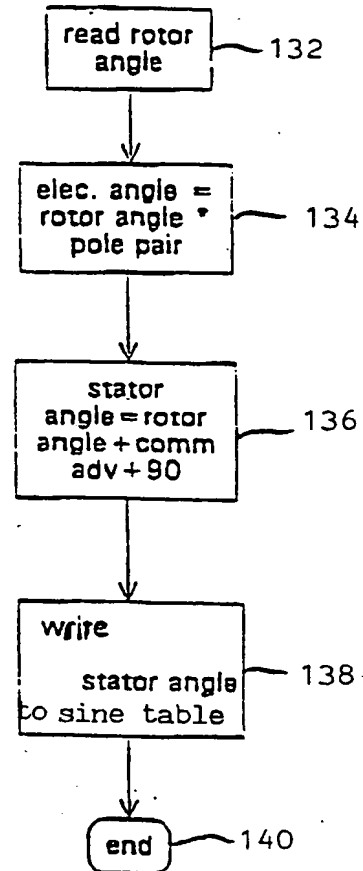


FIG. 10B



THIS PAGE BLANK (USPTO)



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 96 10 8215

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	EP 0 638 988 A (GEORGIA TECH RESEARCH) 15 February 1995 * page 13, line 14 - page 15, line 32 *	1-14	H02P6/10 H02P6/06
A	US 4 651 068 A (S.MESHKAT-RAZAVI) 17 March 1987 * column 6, line 35 - column 7, line 39 *	1,2,4-7, 9,11-14	
D,A	US 4 490 661 A (L.B.BROWN & AL.) 25 December 1984 * claim 1 *	1,6,11, 12,14	
A	GB 2 107 492 A (KOLLMORGEN CORPORATION) 27 April 1983 * claim 18 *	1,6,11, 14	
D,A	& US 4 447 771 A		
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (Int.Cl.6) H02P
Place of search BERLIN		Date of completion of the search 17 February 1998	Examiner Leouffre, M
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>			

EPO FORM 1503 03/82 (P04C01)